PHYSIOLOGICAL FACTORS IN SPACE OPERATIONS

Emphasis on Space Shuttle

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SUMMARY

Efforts to determine the physiological effects of null-gravity space flight on humans began in earnest in 1960 with the establishment of the National Aeronautics and Space Administration's (NASA) Life Sciences Program. The early predictions of life scientists about the physiological effects of null-gravity space flight on man before the first manned space mission ranged from extremely severe to none at all. The majority of the predictions were very pessimistic in terms of current knowledge. It has been proven that, with proper life support systems, man can live and work in the null-gravity environment of space for at least 84 days without serious physiological degradation. The recent Soviet flight of 140 days is the longest time man has remained continuously in this environment. The detailed physiological results of this mission will not be available for some time.

The NASA Life Sciences Program began as an integral part of the United States Manned Space Exploration Program. At first, the life scientists assisted in the selection of astronauts and began to assist in the development of life support systems for space flight. Eventually the life scientists established medical operation procedures and conducted preflight and postflight studies to determine the physiological responses of both animals and men during space flight. The Life Sciences Program basic objective was to assure the health and safety of crewmen.

The Life Sciences Program has been a direct and essential contributor to all manned space flight from Project Mercury to the Apollo-Soyuz Test Project. The understanding that has developed from manned space flight allows mankind to be optimistic about the ultimate accommodation of humans to unlimited space activities. At the same time, however, past research indicates a need to continue the investigations of human physiology in several areas in which potentially serious problems have been identified.

Although many of the space-induced changes found in physiological function are of general interest to the biomedical community, they are of particular concern to the NASA. First, they directly affect considerations about flight safety. Second, these phenomena are associated with healthy rather than diseased individuals; they also concern a select group rather than the general population. These reasons relegate most of the studies of these phenomena to the NASA rather than to other Federal agencies such as the National Institutes of Health.

Problems such as space motion sickness, redistribution of body fluids, and cardiovascular deconditioning are of concern in short-duration Space Shuttle flights. The expanded participation of nonastronaut crewmembers or payload specialists in these flights increases the life scientists' interest in the Space Shuttle flights. Problems such as loss of skeletal mass decreased red blood cell production, and numerous endocrine changes are of more concern on long-duration flights. The Life Sciences Program is therefore concerned with a wide variety of problems that range from the applied to the basic. The common thread is biology; the context is space. Several physiological factors associated with Space Shuttle operations are summarized in this paper including space motion sickness, cardiovascular deconditioning, bone and muscle loss, hematology, fluid and electrolyte changes, reentry g-forces, radiation safety, noise, atmosphere, extravehicular activity, toxicology, nutrition, biowaste, and health maintenance.

DISCUSSION

The Space Shuttle

A new era of space transportation will start in the 1980's with the Space Shuttle's ability to inexpensively transport a variety of payloads into earth orbit. As James Fletcher, the former administrator of NASA, said, "Any discussion of future space initiatives must start with the Space Shuttle, the key to opening near space to quick, easy, and economical access. With the Space Shuttle, operations to and from low-altitude Earth orbit for both manned and unmanned exploration, science, and applications will become routine and relatively inexpensive."

Many participants, representing diverse backgrounds and capabilities, will work routinely in the environment of space, and they will be taken there and returned by the Space Shuttle. The Space Shuttle is being designed and built to take advantage of the most efficient

characteristics of both humans and complex machines. This combination, coupled with the flexible characteristics of the Space Shuttle will provide an efficient system for future national space program activities. With its versatility and reusability, the Space Shuttle will truly open the door to economical and routine use of space.

As a transportation system to Earth orbit, the Space Shuttle will offer the capabilities of such earthbound carriers as trucks and airplanes. The Orbiter is designed to carry into orbit a crew of up to seven, including scientific and technical personnel. On a standard mission, the Orbiter can remain in orbit for 7 days, return to the Earth with personnel and payload, and land like an airplane.

The characteristics of the Space Shuttle will no longer require that the crew be limited to astronauts but will now accommodate scientists and technicians. The maximum acceleration which crewmembers and passengers will experience during launch will be 3g and during a typical reentry 1.5g. These accelerations are about one-third the levels experienced on previous manned space flights; however, the reentry g-component is in the z-axis.

The astronaut and space worker of the future can look forward to many other features of the Space Shuttle including a standard sea-level atmosphere. The nominal duration of a Shuttle mission may be extended to as long as 30 days if the necessary consumables are provided. After the orbital operations, the deorbiting maneuvers are initiated and Shuttle reentry is made into the Earth's atmosphere at a high angle of attack. At low altitude, the Orbiter goes into a horizontal flight path for an aircraft-type approach and landing. A 2-week ground turnaround is the goal for reuse of the Space Shuttle Orbiter. The Space Shuttle may be used in many ways including the operation of satellites, satellites with propulsive stages, space laboratories, or combinations as appropriate.

The Shuttle Orbiter can deliver into orbit a payload of 29,500 kg (65,000 lb). This payload may be up to 18 m (60 ft) long and 5 m (15 ft) wide.[1] The Orbiter is comparable in size and weight to a modern transport aircraft such as the DC-9. It has an empty weight of approximately 68,000 kg (150,000 lb), a length of 37 m (122 ft), and a wing span of 24 m (78 ft). Although the crew compartment is sized for seven crewmembers and passengers, it may hold as many as 10 people in emergency operations. The Orbiter cabin is designed as a combination working and living area. The pressurized crew compartment has a large volume, 71.5 m^3 (2525 ft^3) when compared to the 22 m^3 (600 ft^3) of the Apollo spacecraft. The upper section, or flight deck, contains displays and controls used to pilot, monitor, and control the Orbiter, the integrated Shuttle vehicle, and mission payloads. Seating for as many as four crewmembers can be provided. The midsection contains passenger seating, living area, an airlock, and avionics equipment and compartments. The aft hatch in the airlock provides access to the payload bay.

The payload-handling station, located in the aft section of the flight deck, contains displays and controls required to manipulate, deploy, release, and capture payloads. The person at this station can open and close payload bay doors; deploy the coolant systems radiators, deploy, operate, and stow the manipulator arm; and operate the lights and television cameras mounted in the payload bay. Two closed-circuit television monitors display video from the payload bay television cameras for monitoring payload manipulation.

A versatile extravehicular capability is provided by an airlock, two space suits, and mobility aids. A variety of tasks can be performed during extravehicular activity (EVA) to support either the Orbiter or its payloads.

The Life Sciences Program

The NASA Life Sciences Program principally supports manned space flight and the Space Shuttle in furthering capabilities to exploit and explore space. A major goal of the Life Sciences Program is to understand and reduce any adverse effects of the space environment on humans so that a varied segment of the population can participate directly in space and to develop the foundation for man's extended presence and operations in space. The Life Sciences Program pursues its goals using a diverse set of disciplines. The NASA Life Sciences Program conducts research and development activities that require the services of physicians, biologists, psychologists, chemists, and engineers.

Because of the nature of the physiological changes noted in the null-gravity environment to date, the original full-time physiological monitoring has been supplanted by monitoring only during periods of high activity.[2] More sensitive and elaborate measurement systems are used part-time in an attempt to determine the etiology of some of the subtle physiological changes that have been identified as a result of previous space flight. By the use of more sensitive physiological measurement tools, several additional subtle physiological changes will no doubt be revealed. It is important to note that all physiological changes detected in space thus far were completely reversible. That is, the physiology returned to normal within a very brief period, usually a few days after return to Earth. A healthy crewman's ability to adapt to the null-gravity environment and to readapt to the one-g environment has proven to be excellent.

The physiological changes observed have been so subtle that the detection frequently required sensitive instruments coupled with the use of provocative tests such as tilt tables, lower body negative pressure devices, bicycle ergometers, and rotating chairs. In view of the rather minimal physiological changes induced by null-gravity space flight to date, the question arises as to what sort of physiological measurements should be made on future space travel. On the relatively brief flights, monitoring of the crewmen during high-activity

periods will suffice supplemented by selected, well-planned, mission compatible, medical studies.

On February 7, 1978, the NASA issued an Announcement of Opportunity for Life Sciences investigations on dedicated Space Shuttle/Spacelab Missions 1981 through 1983.[3] In it appeared the following excerpt from the National Academy of Sciences study, Scientific Uses of the Space Shuttle (Space Sciences Board, National Research Council, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418, 1974, page 154).

> "The Shuttle Era will provide the first opportunity to carry out a thorough experimental program in the life sciences under conditions approximating those of ground-based laboratories . . . . In addition to biomedical investigations relevant to man's well-being in space, the basic principles of biology and medicine can be examined using the zero-gravity environment as a research tool."

The NASA plans to make the Shuttle the basis of a highly versatile space life sciences laboratory capable of supporting applied and basic biological, biomedical, behavioral, and technological investigations. The NASA has received many flight experiment proposals as a result of this announcement. Those flight experiments selected as a result of the announcement will undergo a detailed definition study before final flight assignments are made. Because several space flights were covered by the announcement, the investigators were encouraged to propose multimission experiments if needed.

The primary areas of research to be pursued in space and on the ground are space motion sickness, cardiovascular deconditioning, bone mineral loss, muscle loss, red blood cell loss, and fluid and electrolyte loss. These areas of current emphasis have emerged from systematic examination of bodily systems in prior manned spaceflight experiments. In addition to the major areas of research in the life sciences for the Shuttle Era, one should note that considerable interest exists in the physiology of the reentry G_z-forces exerted on the crewmen and passengers; of radiation exposure; and of environmental factors such as noise, atmosphere, EVA prebreathing, hygiene, and toxicology. Additional operational factors, such as food, nutrition, and health stabilization will also be investigated. Each of these factors associated with manned space flight will be reviewed and its mission effect, if any, will be noted.

Space Motion Sickness

The absence of Earth gravity during space flight has a potential effect on those sensory systems that are gravity- or acceleration-sensitive, such as the vestibular system. Physiological problems involving the vestibular system have been observed during previous manned space flights, the most striking problem being space motion sickness. Approximately 30 percent of the Apollo and 55 percent of the Skylab crewmembers experienced some symptoms of space motion sickness during space flight. In all cases, the symptoms of space motion sickness were confined to the early portion of the flight and complete recovery had taken place within 3 to 5 days of the start of the mission.[4]

During the Space Shuttle operations, three factors increase concern about the incidence of space motion sickness that is anticipated.

1. Many Space Shuttle flights will be short duration with high workloads planned during the initial days in orbit. Performance decrements due to illness could easily affect mission success.

2. The increased volume of Shuttle will permit extensive movement by the crewmembers. It is postulated that this movement may contribute to the onset of symptoms of space motion sickness.

3. Space Shuttle crews and passengers will include a significant number of individuals previously inexperienced with the unusual gravito-inertial force environments. This inexperience with the null-gravity environment of space could contribute to the onset of symptoms of space motion sickness in a higher percentage of the individuals onboard. Most life scientists agree that better understanding of the causes of space motion sickness will be essential to the ultimate development for means of its control, and as a result the NASA has initiated a program of ground-based research with humans and animals. These research studies will use appropriate electrophysiological neuroanatomical, behavioral, and biochemical methodologies.

In pursuing these studies, attention will be focused on two prevailing theories on the cause of space motion sickness. One of these, the sensory conflict theory, postulates that the sickness is the result of a neural mismatch between the information received from the spatial senses and that from previous experience. The second, the fluid shift theory, postulates that space motion sickness results from the headward shift of body fluids in weightlessness and the ensuing pressure changes in the labyrinthine fluids.

Flight experiments will be needed to investigate and confirm in null gravity the hypotheses that cannot be adequately studied in the one-g laboratory of Earth. Three such vestibular flight experiments to examine the sensory conflict hypothesis are planned for the first Spacelab flight, and additional investigations will be done on the ensuing dedicated flights.

Research on the development of predictors of susceptibility to space motion sickness will focus on several related approaches. One of these involves attempts to establish positive correlations between susceptibilities in different provocative test environments. Particular

emphasis is being placed on the use of stimuli that introduce sensory conflict and on comparisons between susceptibility during ground-based test and null-gravity parabolic flight. Another approach is to determine the correlation between susceptibility and other response parameters such as vestibular reflexes, psychodynamic traits, and biochemical factors. Finally, innate or learned behavioral and physiological adaptability to stressful environments is being evaluated as having possible predictive value. Despite the insights that should be gained as a result of these ground-based studies, it is anticipated that the final validation of predictive tests will require a series of controlled experiments with individuals who will fly on Space Shuttle missions. Many needed elements of this validation process are embodied in a test program which is currently under development and which will commence with the Shuttle flights during the Orbital Flight Test (OFT) phase.

Two approaches are being followed with regard to the development of effective countermeasures for space motion sickness. The most promising of these at present involves the use of anti-motion sickness medications. Advances have been made in the identification of highly effective drugs that can be administered orally, transdermally, or intramuscularly. Research is being pursued to establish the overall efficacy of these drugs in different provocative motion environments. Despite their usefulness, anti-motion sickness drugs may exact penalties in the form of detrimental side effects. Therefore, additional research is required to examine more thoroughly the behavioral and physiological consequences of using drugs as a countermeasure.

In addition to drugs, the development of practical vestibular adaptation training methods continues to be of great interest. In this area, efforts are being made to acquire more information related to the acquisition, retention, and transfer of adaptation. With regard to training, unique research that uses biofeedback techniques is being performed. As with predictive tests, the final validation of countermeasures for space motion sickness, especially those using training techniques, will require a series of controlled studies with individuals who fly on Space Shuttle missions.

In the future, studies should consider the possible consequences of very long duration exposure to null gravity. This issue involves potential irreversible or very slowly reversing functional and/or anatomical alterations that may occur in the gravity receptors, especially the otolith organs. Such alterations could lead to perceptual illusions, ataxia, dysequilibrium, and motion sickness upon return to one-g. Ground-based studies may shed light on these potential effects. On the basis of previous spaceflight data, it is evident that cardiovascular changes have accrued as a consequence of null-gravity exposure. These changes, collectively referred to as cardiovascular deconditioning, include orthostatic intolerance, decreased exercise capacity, and decreases in circulatory blood volume. They have been observed in all crewmembers on return to the one-g environment, even on some very short missions.

It has been hypothesized that exercise may be a partial countermeasure to cardiovascular deconditioning. The Shuttle crewmembers will have access to two types of exercise devices: a treadmill device and a bungy-cord exerciser. The series of events that occur in the cardiovascular system following crew insertion into null-gravity, during adaptation to null gravity, and following return to one-g are complex and only partly understood. It is evident, however, that fluid is displaced from the lower extremities to the central circulation.(5) It is postulated that a series of reflex and mechanical changes occurs as secondary responses to this headward fluid shift. The most obvious results are a decrease in circulatory blood volume and a decreased tone in the peripheral blood vessels. During and following reentry, the cardiovascular system (which has adapted to the absence of gravity) is subjected to a one-g force. The main concerns center on the ability to maintain adequate blood pressure and cerebral circulation during these periods.

Most near-term research is directed toward preventing orthostatic intolerance during Shuttle reentry through the use of anti-g garments or other treatment regimens. Results from ground-based research suggest that in-flight lower body negative pressure training, fluid and electrolyte supplementation, and/or vasoconstrictive and salt-retaining drug therapy may be effective in preventing the problem.

To understand more fully the mechanisms that occur during cardiovascular deconditioning, a series of spaceflight experiments has been proposed. Studies are planned to measure regional blood flow and volume during the transitional periods from one-g to null gravity and back to one-g. Continuous or rapidly repetitive measurements taken during the early Space Shuttle flights will document the time course of the fluid shifts and the changes in cardiovascular function that accompany them. Invasive studies in animal models will yield detailed information on changes in regional blood flow.

Bone and Muscle Loss

It was demonstrated during the Skylab missions that calcium was lost during flight.(6) The rate of calcium loss did not appear to diminish over nearly 3 months. The calcium is primarily lost from bone. Bone mineral loss may ultimately limit the time humans can endure weightlessness without the possibility of increasing the incidence of bone fracture. Numerous secondary effects of this mineral loss could be of great consequence. The prolonged elevation of serum and urinary calcium levels could give rise to renal disturbances and calculi (kidney stones). Calcium deposition could take place in other organs with harmful effects.

In addition to calcium loss, a substantial degree of muscle atrophy has occurred in space flight. These changes occur in selective muscles of the lower limbs. Of concern with both

muscle and bone loss are the possibilities of permanent structural change and the possibility that repeated exposure to null gravity results in a progressive and irreplaceable bone mineral loss.

Current research on bone and muscle loss is focused on ground-based studies. Prolonged, enforced bedrest is a reasonable null-gravity model for calcium studies in the human. These studies, have made it possible to eliminate several potential countermeasures from further consideration. Current work is focusing upon pharmacologic intervention.

Shuttle-launched space flight experiments will accelerate work on both human and experimental animals. Both invasive and newly developed noninvasive techniques will be used to better understand and, it is hoped, to prevent the calcium loss.

The approach to the muscle loss problem is somewhat different. Animal models can be used to study atrophy in selected muscle groups. Invasive techniques are being used in ground-based studies to understand the biochemical and enzymatic correlates of this atrophy. These studies may lead to an understanding of exercise and perhaps even of antimyopathic agents.

Red Blood Cell Mass

The most significant effect of the space flight environment on the blood and blood-forming tissues of man has been a consistent reduction in the circulating red blood cell mass during all flight intervals. Data from the Skylab flights indicate that the high oxygen level used in earlier vehicles is not the cause. It appears that some other characteristics of the space flight environment causes a suppression of red blood cell production.

Research tasks are directed toward understanding why red blood cell production is suppressed in space flight. Of equal interest are the associated changes in cellular shape, overall metabolism, and membrane function.

Detailed human studies involving serial sampling in flight and detailed analysis on the ground will be performed on Shuttle missions. In addition active experiments involving radioactive tracers and tissue samples, detailed examination and study of bone marrow, spleen, and lymph nodes will be conducted on animal models. Current ground-based work is examining possible models that would be appropriate for such studies.

Fluid and Electrolyte Changes

It has been demonstrated that exposure to weightlessness results in a redistribution of the volume of blood within the vascular system. This redistribution is interpreted as an increase in blood volume by sensory receptors located in the heart, thus initiating a compensatory loss in water, sodium, and potassium from the renal tubules. This loss of water and salt has been manifested during every space flight as a loss in body weight, most of which is rapidly regained postflight.

Associated with the redistribution of fluid is a series of endocrine and hormone changes. A coordinated plan using ground-based and flight experiments has been developed to address the fluid and electrolyte concerns. Because the onset of fluid redistribution occurs immediately upon entry into the null-gravity state, the Spacelab flight experiments are designed to gather data from the earliest moments of weightlessness. In addition to documenting the natural history of the many known responses, attention will be paid to the complex array of secondary hormone and endocrine responses that appear to be initiated.

Reentry G-Forces

It should be noted that previous United States manned spacecraft reentries have been performed in such a manner that the majority of the g-forces were in the X-vector. In past space flights, this meant that during reentry the blood did not have a tendency to pool in the legs. During Shuttle flights, reentry will be made such that the crewmembers will encounter a fairly long-duration exposure (20 minutes) of low-level +1.5 to +1.8 g_z before landing. It is possible that a combination of the cardiovascular deconditioning that occurs fairly early in the null-gravity space flight will result in some of the crewmen or passengers becoming hypotensive during reentry in the Shuttle with a positive g_z stress. As a result of this consideration, it has been decided that during the OFT phase of Shuttle operations all crewmen will wear anti-g suits during reentry.

The NASA is currently conducting a series of bedrest simulations of a 7-day Shuttle mission. In these tests, a centrifuge is used to simulate the reentry gravitational stress profile of the Space Shuttle. The subjects were placed in two groups. One group was exposed to the nominal Shuttle reentry profile (at least as far as gravity is concerned) on the centrifuge and the other group was exposed to the nominal Shuttle reentry profile with an anti-g suit inflated.

Preliminary results of these studies indicate that, with the level of deconditioning produced by bedrest, the subjects may tolerate the 1.5g profile with or without the anti-g suit. However, the anti-g suit does offer protection if the g-loads are increased above 2.5g. Although bedrest remains one of the best simulations of the null-gravity exposure, it is far from perfect. In fact, the cardiovascular changes noted after bedrest are often somewhat different from those noted by those who have experienced null-gravity space flight.

Therefore, it is considered necessary in many instances to conduct critical testing in the operational environment to assure that conclusions drawn are valid.

The NASA is considering the investigation of the physiological effects of anti-g suits during Shuttle reentry. During this test, crewmembers other than the pilot and co-pilot will be used as test subjects. Each subject will serve as his or her own control because the g-tolerance varies greatly between individuals. Each subject would be noninvasively instrumented to permit quantitation of certain vital physiological parameters during Shuttle reentry. The plan calls for monitoring the electrocardiogram, temporal arterial blood flow, brachial artery pressure, and anti-g suit bladder pressures. It is anticipated that the results of this study during the OFT phase of Shuttle operations should answer the question whether or not anti-g suits need be worn during Shuttle reentry.

Radiation Safety

The NASA has had few problems with space radiation exposure in the past. As an example, the average radiation dose for crewmembers on Apollo missions averaged about 0.4 rad.(7) This is approximately equivalent to the cosmic radiation dose experienced by U.S. citizens living at 2000 m altitude for a period of 2 years. Crews on the Skylab mission also received minimal doses of radiation; for example, it is calculated that the Skylab 4 crewmen could fly one 84-day mission a year for 50 years before exceeding their career limits. The NASA career limits during Skylab were 400 rem for blood-forming organs, 1200 rem for skin and 600 rem for eye lens.

The objective of the JSC Radiological Health Program is to avoid the harmful effects of radiation by limiting the exposure to the lowest possible level. Levels of exposure on the ground are to be consistent with industrial levels controlled by the Nuclear Regulatory Commission, and space radiations affecting the crew and other space workers should be negligible in terms of significant biological effects as defined by the National Academy of Science. To achieve these goals requires constant coordination between the radiological health staff, spacecraft designers, mission planners, and persons exposed to radiation.

Unique aspects of space radiation (high-energy particles) requires that the NASA support a continuing radiobiological research effort in this area. This research is coordinated with other Federal agencies having problems of a similar nature.

Astronauts will encounter a wide variety of ionizing radiations in space. The potential for harmful biological effects from these radiations depends upon the biologically effective dose which, in turn, depends on numerous factors.

A computer program has been developed which models the expected mission doses from major sources such as the electrons and protons in the trapped radiation belts and their secondary bremsstrahlung (X-rays) produced in spacecraft components. Other models project the expected doses from solar particle events if some information about the size and characteristics of the event is known shortly after its onset. It is not yet possible to predict the occurrence of a solar particle event, but the probability of one occurring is calculable. Additional models are used for projecting the major fraction of the dose from galactic cosmic radiation for particular missions at particular times in the sunspot cycle.

Because of the uncertainties in the existing models, the radiological health strategy does not rely solely on calculations. Onboard dosimetry is also provided for the following reasons: (1) to verify projections, (2) to refine computer models and projections, (3) to obtain accurate dosimetry from unexpected (and poorly modeled) events such as (a) solar particle events, (b) nuclear detonations, (c) accidental releases of radioactive material, which may be used in payload experiments, and (d) leakage of radiation from onboard sources (e.g., radioactive thermoelectric generators, nuclear power reactors, sealed sources used in experiments, radioluminescent devices, etc.).

Not only are dosimeters needed for unexpected events and verification and refinement of modeled dose projections, but they serve as part of the medical record of each astronaut and thus are useful in evaluating the contribution of radiation to any future health problems.

For OFT flights, the expected doses or dose equivalents will be quite low ((less than 10 m rem (1 rem) barring a severe solar particle event)), so use of calculated spectral parameters with minimal onboard dosimetry and conservative assumptions for obtaining a worst-case estimate of dose equivalents will be adequate for radiological health and will not severely affect budgeting of career dose equivalents.

Noise

During the Apollo Program, a special study was implemented by JSC life scientists to evaluate quantitatively the effects of lunar module noise on crew sleep and hearing. During the Skylab Program, life sciences personnel were actively involved in specifying noise limits for the Skylab workshop, monitoring contractor activities pertaining to spacecraft ground-based noise testing, participating in activities involving the actual collection of in-flight noise data, and collecting preflight immediate postflight audiograms on the crewmen on each mission.

On the basis of data previously acquired, it is known that, with a few minor exceptions, the Apollo and especially the Skylab spacecraft internal noise environments were within

acceptable limits. The ambient noise present in these vehicles at no time presented a hazard to the crewmen's hearing and seldom interfered with the crewmen's ability to effectively communicate perform, and obtain adequate sleep.

Presently estimated Shuttle noise levels, particularly those anticipated for the OFT phase are higher than those specified by NASA. The design limit for Shuttle on-orbit acoustical noise is a noise spectrum equivalent to the NC-50 level.(8) The NC-50 level, which defines a group of octave-band sound-pressure-level limits from 63.5 to 8000 Hz, is the upper limit for spacecraft ambient noise. It is important to understand that the NC-50 level is approximately equivalent to 55 dBA. The A-weighted sound pressure level will always be approximately 5 dB higher than the specified NC level. When dealing with sound that affects humans, the A-weighted level is customarily used because it takes into account the physiological filtering and sound transduction properties of the human ear.

The projected noise levels for the first OFT crew module will be about 82 dBA in the middeck area and 73 dBA on the flight deck. These levels are approximately equivalent to NC-77 and NC-68, respectively. Furthermore, the projected noise spectrum peaks at 2 KHz, which is in the most sensitive region of the human auditory system. The noise levels projected for the Shuttle OFT missions have a definite potential for causing detrimental physiological effects on at least some crewmen.

Using the best available sources of information, it has been determined that continuous exposure to noise levels greater than 76 dBA for periods longer than 24 to 48 hours could cause permanent damage in some individuals. Thus, 82-dBA level projected for the Orbiter middeck area represents a problem.

To reduce the Shuttle OFT on-orbit noise to acceptable levels, several actions are being pursued. These include the design and fabrication of foam-lined equipment mufflers that could be installed in the vehicle before the first OFT mission, the use of sound-attenuating material in the sleep compartment curtains, and the covering of openings in the avionics bay and other areas with easily removed noise-attenuating "patches."

All these engineering fixes to the vehicle hardware are very highly desirable and every reasonable effort is being made to implement these corrective measures. They are much preferred as compared to requiring the crewmembers to wear some type of hearing protection device (eg., ear plugs or muffs). Hearing protectors, even if properly fitted, can after a period of prolonged use become a source of discomfort and may, if improperly designed, interfere with the receipt of important auditory information.

Shuttle Atmosphere

The Orbiter and the Spacelab will have a 10.1×10^4 N/m^2 (14.7 psia) environment with two-gas control.(9) In this regard, it will more closely approach a sea-level laboratory environment than prior U.S. spacecraft. The life scientists specified a two-gas Earth-pressure environment particularly for the medical experiments. Engineering considerations also favored an Earth-normal environment. Pressure affects the heat capacity and viscosity of gases and thereby affects the performance of fans in the environmental control system and the cooling requirements of electronics in general.

Oxygen partial pressure in both the Orbiter and the Spacelab will be 22×10^3 N/m^2 $\pm$ 17.2×10^2 N/m^2 (3.2 $\pm$ 0.25 psia), a variation considerably greater than that due to changes in atmospheric pressure at a sea-level laboratory but providing a higher oxygen level than laboratories at higher altitudes.

The carbon dioxide partial pressure requirement for Shuttle is 0 to 1.013×10^3 N/m^2 (0 to 7.6 mm Hg) with a nominal value of 6.6×10^2 N/m^2 (5 mm Hg) stated as nominal for the Spacelab. This level is consistent with levels on prior spacecraft.

The temperature within the Shuttle will be selected by thermostat $\pm$1.1 K (2° F) within a range of 291 to 300 K (65° to 80° F). Temperature control has been acceptable on prior spacecraft. However, the Shuttle temperature control will represent an improvement and will compare well with the temperature control of any well-designed air-conditioned office building or general-purpose laboratory. The selectability of temperature in Spacelab will allow optimization of the temperature environment and may be used to provide reliable $\pm$1.1 K (2° F) controlled conditions within 291 to 300 K (65° to 80° F) range for specific experiments.

The permissible humidity ranges are 8.0 to 10^2 N/m^2 to 18.6×10^2 N/m^2 partial pressure of water (6 to 14 mm Hg) for the Orbiter and 9.3×10^2 N/m^2 partial pressure of water (7 mm Hg) to 70 percent relative humidity for Spacelab. The humidity will not be directly controllable.

The air motion requirements for Shuttle are 8 m/min (25 ft/min) and within a range of 5 to 12 m/min (15 to 40 ft/min). The absence of free convection in null gravity imposes a change in the environment that is not spacecraft controlled. The minimum air motion will provide forced air motion near that provided by free convection.

Extravehicular Activity

Because of experience with extravehicular activity and the usefulness of EVA, this capability has been retained in the Space Shuttle Program and refers to activities for which

crewmembers don their space suits and life support systems and then exit the Orbiter cabin to perform operations inside or outside the payload bay. EVA may be categorized as follows: planned before launch; unscheduled; and contingency, required to effect the safe return of all crewmembers. Current planning calls for each Orbiter mission to provide the equipment and consumables required for three two-man EVA operations, each lasting a maximum of 6 hours.(10)

The airlock provides the means of transfer from the shirt-sleeve environment of the cabin to the vacuum environment of space and contains the pressurization and depressurization systems necessary to effect such a transition. The airlock is removable and can be installed in one of three different Orbiter locations, depending upon the payload. The basic airlock location is inside the middeck compartment to permit maximum use of the payload bay volume. An extravehicular mobility unit, consisting of a self-contained life support system, provides a breathing environment at a pressure of 2.76×10^4 N/m^2 (4 psia) and incorporates provisions for internal liquid cooling, communicates equipment, special EVA helmet visor protection, and external restraint and tethering fittings.

Extravehicular activity must be preceded by an uninterrupted 3-hour period of prebreathing pure oxygen. Prebreathing pure oxygen for 3 hours is required to assure denitrogenation before operating in a 100 percent oxygen environment at reduced atmospheric pressure. For example, if no prebreathing period were included before the EVA, the occurrence of serious bends would be approximately 30 percent depending upon the individual and the EVA work level. It is also essential that the prebreathing period be uninterrupted; that is, that the subject continue to breathe 100 percent oxygen. For example, a 1-minute break close to the 3-hour mark in the prebreathing cycle would require a 30-minute "payback" time such that egress would not occur until 3 hours and 30 minutes had elapsed. However, normal crew procedures anticipate about 15 minutes from donning of the helmet to depressurization. If the suit purge began at the 3-hour mark, a total of 30 minutes (i.e., an additional 15 minutes) would be required before depressurization. It should be noted that complete prevention of the incidence of bends in an unselected population during an operational depressurization from $10.1 \pm 0.1 \times 10^4$ N/m^2 (14.7 $\pm$0.2 psi) cabin atmosphere to a $2.76 \pm 0.1 \times 10^4$ N/m^2 (4.0 $\pm$0.2 psi) suit environment would require prebreathing times of from 10 to 12 hours. The 3-hour value that was established as a Shuttle specification assumes that the crew will be relatively bends resistant. The factors that lead to being resistant to bends include having a low fat to lean body mass ratio, being in good physical condition, and remaining free of bends symptoms during altitude chamber training. It is further assumed that EVA metabolic rates will not exceed the moderate levels experienced during Apollo missions. The 3-hour prebreathing period that is scheduled for Shuttle EVA provides a 95 percent confidence level.

The following typical EVA tasks demonstate the range of EVA opportunities available on Shuttle:

Inspection, photography, and the possible manual override of vehicle and payload systems, mechanisms, and components

Installation, removal, or transfer of film cassettes, material samples, protective covers, instrumentation, or launch and reentry tiedowns

Operation of equipment, including tools, cameras, and cleaning devices

Cleaning of optical surfaces

Connection, disconnection, and stowage of fluid and electrical umbilicals

Repair, replacement, and calibration of modular equipment and instrumentation on spacecraft or payloads

Deployment, retraction, or repositioning of antennas, booms, and solar panels

Attachment and release of crew equipment restraints

Performance of experiments

Cargo transfer

With the manned maneuvering unit, a propulsive backpack device, an EVA crewman can reach areas beyond the payload bay which he could not reach otherwise. The unit, a modular device stowed in the payload bay and readily attached to the extravehicular mobility unit, can be donned, doffed, and serviced by a single crewmember as needed during the EVA period. Because the manned maneuvering unit has 6-degree-of-freedom control authority, an automatic altitude-hold capability, and electrical outlets for such ancillary equipment as power tools, a portable light, cameras, and instrument-monitoring devices; the unit is quite versatile and adaptable to many payload task requirements.

Toxicology

Space toxicology focuses on ensuring that the space crew is not exposed to any toxic hazards while on a mission. The major areas of concern are the accumulation of toxic substances that are emitted in trace levels by various substances in the spacecraft, and ingestion of toxic substances contained in the drinking water system. In practice measures used to ensure crew toxicology protection are preventive in nature. A spacecraft material selection

program has been established for the purpose of reducing the quantity of nonmetallic materials acceptable for space flight, particularly those that could be serious offgassing sources. Material selection programs are conducted on both the Orbiter and the Spacelab Requirements for the programs are contained in NASA Handbook 8060.1A "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion." Materials that fail these requirements are still needed for space flight use and are handled individually under a provision known as materials-usage agreements. This provision allows a closer toxicological assessment of a given material.

The NASA Toxicology Laboratory is provided with a sample of the candidate material and a thorough analysis of its toxic products is performed. Near the completion of the Shuttle Orbiter, a special offgassing test is performed in which all onboard equipment is brought to operating temperature and a special measurement of the offgassing of the spacecraft materials is completed. During these offgassing tests, the Orbiter cabin is closed so that no exchange of air is permitted with the outside atmosphere. All possible heat-producing equipment is energized before the beginning of the test period. The test is conducted with a maximal amount of flight equipment onboard the vehicle. The Shuttle life support system or environmental control system is activated during a portion of the test.

In addition to special materials testing and full testing for the Shuttle, the NASA Toxicology Program provides the maximum permitted concentration levels of contaminant gas for Orbiter design. The environmental control system contains a lithium hydroxide canister for the control and scrubbing of carbon dioxide from the cabin atmosphere. In addition, a catalytic oxidizer has been added to the environmental control system for the removal of carbon monoxide.

Special consideration is given to the compressed and cryogenic breathing gas supplies flown on the Shuttle. These gases are screened to assure that they do not contain excessive levels of trace contaminants.

Contaminant gases produced by pyrolysis or combustion of nonmetallic materials is very difficult to predict. If a problem on the Shuttle develops in which a fire is suspected, the crew immediately dons a mask that provides access to protected contaminant-free breathing gas.

During space flight, gas samples will be taken at the beginning, middle, and end of the mission. The absorbent trapped samples will be collected in flight and analyzed on return to the Earth. In later missions, the Space Shuttle may carry a trace gas analyzer that will provide real-time information concerning onboard trace contaminant gases. Common component trace gases found in spacecraft environments include acetone, ammonia, benzene, butyl alcohol, and carbon monoxide.

Food and Nutrition

Initially, concern existed for the mechanics of eating and eliminating in weightless flight. The space flight experience of American and Soviet pilots largely has dispelled these fears. Indeed, their observations validated the previous findings of aircraft experimenters flying parabolic maneuvers, that is, that physiological mechanisms of food ingestion are not very sensitive to gravity. Although the absence of gravity restricted the choice of some foods and constrained the design of packages, once food was in the mouth, the subsequent steps of swallowing, digestion, and elimination appear to proceed in a normal fashion. The Skylab crews performed a control study to determine whether any changes in the physiological response to taste or aroma occurred during weightless flight. These tests provided no indication or evidence of any change in the ability to identify aromas. Furthermore, no evidence in any of these data suggested that weightlessness is a significant factor influencing the flavor of food.

A determination of energy requirements is crucial to the design of life support systems and to overall assessment of man's ability to live in weightlessness. It might seem logical to assume that activity in weightlessness would require less energy than in one-g because the counteracting force of gravity would be eliminated. Although locomotion in reduced and null gravity requires less energy than at one-g, those tasks that ordinarily depend on friction for their reactive force require muscular work to supply that force. In addition, very little of man's basal energy expenditure is attributable to direct gravity effects. Examination of data acquired during the Skylab missions reveals that the overall energy consumption in flight is not statistically different from that observed on the ground.

On Skylab, each of the 70 or so individual foods that were provided was analyzed for all known nutrients, including individual amino and fatty acid. Carbohydrate consumption was generally higher in flight than on the ground with averages of 400 grams per day and 350 grams per day respectively. Fat intake in flight was lower on an isocaloric basis. Crude fiber intakes were about 5 to 10 grams per day in flight and on the ground. Based on experience with previous space flights, the Shuttle food system is designed to provide crew nutritional energy requirements for good health and effective performance. To maintain good nutrition, each crewmember should consume at least the following quantities of nutrients each day.[11]

Protein	(g)	56	Vitamin B_{12}	(μg)	3.0
Vitamin A	(iu)	5000	Calcium	(mg)	800
Vitamin D	(iu)	400	Phosphorus	(mg)	800
Vitamin E	(iu)	15	Iodine	(μg)	130
Ascorbic Acid	(mg)	45	Iron	(mg)	18

Folacin	(µg)	400	Magnesium	(mg)	350
Niacin	(mg)	18	Zinc	(mg)	15
Riboflavin	(mg)	1.8	Potassium	(meq)	70
Thiamin	(mg)	1.4	Sodium	(meq)	150
Vitamin B_6	(mg)	2.0			

Diets will be based on a variety of common foods to provide other nutrients for which human requirements have not been well defined. Current planning stipulates that 3000 kilocalories per day will be provided. However, the total energy content of the diet will be predicted upon an accurate estimate of each crewmember's lean body mass in accordance with formulas for energy utilization in weightlessness. The constituents of the Shuttle food will be known quantitatively. The various sources from which the NASA obtains these data include manufacturers' specifications, the U.S. Department of Agriculture, and the Food and Drug Administration, and in some cases based on special tests.

Health Stabilization for Orbital Flight Tests

The purpose of the Health Stabilization Program for the OFT missions is to maintain the health of the crewmen during the critical period just before launch. The objective of the program is to minimize and to preclude, if possible, exposures to infectious diseases for all flight personnel. The Health Stabilization Program will be made operational during a 7-day period immediately preceding launch of each OFT mission.

A reduction in the number of isolation days from earlier missions is the approach for the OFT phase. On past missions, 80 to 85 percent of the illnesses reported by primary contacts were upper respiratory illnesses. The incubation for most of these illnesses range from 3 to 5 days. With a 7-day isolation period, this type of illness can be detected in the crewmen before launch. Further exposures to upper respiratory infection, which could cause in-flight crew illness, can be prevented

The excellent results obtained with this program on past missions attest to the fact that the individual efforts by primary contacts and crewmen have been outstanding. Since the program was initiated, an infectious illness has not occurred in any crewmen during the time of coverage.

It is expected that the Health Stabilization Program as presently defined will not be routinely implemented subsequent to the OFT phase. Specific operational Shuttle missions may be defined for which it will be necessary to provide some form of health stabilization. As such missions become better defined, the required plans will be developed to support such flights. To assure appropriate health stabilization measures for the operational Shuttle Era, the Space and Life Sciences Directorate of the Johnson Space Center has established and will maintain a committee to determine the need for health stabilization for each flight.

Shuttle Biowaste

Spaceflight waste management systems have progressed from the simple bag collection systems flown in Mercury, Gemini, and Apollo to the relatively sophisticated systems used in Skylab and planned for use on Shuttle. The Shuttle biowaste collection system provides for the collection of urine and feces and for disposal. This biowaste system can process waste from both males and females as well as process waste water from the personal hygiene station and from the portable life support system.(12) The system is located in a privacy compartment on the middeck of the Shuttle Orbiter.

The Shuttle biowaste system can be used in a standing or sitting position. The urine is conveyed into the system and the liquid-air mixture is separated by a centrifugal separator from which the air is pumped out of the unit through an odor and bacteria filter. The urine flows from the separator to the waste water tank.

The system configuration provides for combined micturation and defication. In this process the user positions himself on the seat using the seat and foot restraints. The urine is processed as previously described. The feces and tissue used in cleaning are conveyed into the waste management system by way of air flow. The solid wastes are accelerated into a rotating slinger, where the feces adheres to the inner wall in a thin layer around the periphery. The transport air flow exits the commode by way of a bacteria filter at the base. Completion of this process is followed by a semi-automatic water flush for cross-contamination control.

Work/Rest Cycles

Flight planning for Shuttle space flights includes the details of the work/rest cycles. Nominally eight hours will be set aside for sleep and 16 hours for activity, which includes time to eat, work, and rest or exercise. Some Shuttle missions may require two-shift operation.(13) Two-shift operation onboard Shuttle could present some problems in that the rest cycle for some crewmen may be interrupted by the activity cycle for the other crewmembers. For the two-cycle mode of operation the Shuttle sleep stations will be configured so that they limit extraneous noises and light

For the two-shift mode of operation it will be necessary to interrupt and change the circadian rhythm pattern of some of the crewmen during the mission. During launch the crewmen will be on a standard work rest cycle. It is anticipated that subsequent to launch these

cycles will have to be adjusted fairly rapidly so that the two-shift operation may be accommodated on board. Prior to return it will be necessary for another adjustment to return to a single-shift operation just prior to reentry.

Crew Health Maintenance

NASA medical personnel are responsible for the health of all persons flying in NASA spacecraft. This includes the application of principles of preventive medicine as well as the treatment of any illnesses or injuries which may occur as a result of space flight. All personnel who fly on NASA spacecraft must hold a current NASA medical certification. The following classifications are currently in use: Class I for pilot astronauts, Class II for mission specialists astronauts, and Class III for payload specialists. During the orbital flight phase each crewman will have four preflight examinations. These evaluations will start 30 days prior to the flight and will be concluded on launch morning. The protocols for these preflight medical evaluations include a dental exam, a medical history, a physical, and laboratory and stress tests.

During the orbital test flight phase there is a Health Stabilization Program which is designed to maintain the health of mission crewmen during critical mission time periods. The objective of the program is to minimize and to exclude, if possible, infectious disease exposures to all flight personnel. The program will be operational during a 7-day period immediately preceding the launch of each Orbiter Flight Test.(14)

Inflight medical support involves trained personnel who have access to the onboard medical kit. One of the crewmembers onboard will be responsible for the onboard medical kit and will be able to communicate with a physician in mission control who in turn has access to a variety of medical consultants. The Shuttle Orbiter medical kit weighs approximately 9 pounds and includes those items which are necessary to treat most minor illnesses and injuries.

Several postflight medical evaluations will be conducted on each crewmember. The first examination will be conducted within 12 hours after landing. The postflight medical examinations include a medical debriefing, a physical examination, and laboratory examination. The returning crewmen may fly in high performance aircraft as a passenger only after certification by the crew surgeon. They may fly as pilot in command of an aircraft after successful completion of an instructor pilot checkout.

The orbital flight test phase of Space Shuttle operations will require the mobilization of an emergency medical service system in support of launch and landing operations. Emergency medical services will be provided to respond to the individual crewmember's need for immediate medical care. If required, the crewmember will have access to a comprehensive inpatient medical care facility capable of treating injuries or illnesses. One of the key elements of the emergency medical services system is a communications capability linking all members of the system.

CONCLUSION

The Space Shuttle has been designed to provide the crewmembers with a safe and comfortable environment in which to work and rest. Past space flight experience has shown that with the proper life support systems man can live and work in the full-gravity environment of space for many days without serious physiological degradation. The physiological changes that the Shuttle crewmembers will experience are, for the most part, predictable and in some cases there are corrective measures which may be taken. Based on previous space flight experience, and given the characteristics of the Space Shuttle the anticipated physiological changes should not give rise to any serious problems or any long-term irreversible effects.

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